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Ministry of Transportation
Materials Engineering and Research Office Report

# Recommended Practice For Establishing Rock Elevation For New Highway Construction

MERO-030

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# Recommended Practice For Establishing Rock Elevation For New Highway Construction

**Author(s)** Robert G. Gorman, Chris A. Rogers

**Originating Office** Soils and Aggregates Section, Materials Engineering and Research Office

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**Ministry Contact** Robert G. Gorman, Chris A. Rogers
Soils and Aggregates Section, Materials Engineering and Research Office
Highway Standards Branch, Ontario Ministry of Transportation
Room 220, 1201 Wilson Avenue, Downsview, Ontario, Canada M3M 1J6
Tel: (416) 235-3736/(416) 235-3734/Fax: (416) 235-4101
e-mail: Bob.Gorman@mto.gov.on.ca/Chris.Rogers@mto.gov.on.ca

**Abstract**

The establishment of accurate rock line evaluations for new highway construction has traditionally been a challenging task facing highway designers in many parts of the province. Inaccurate rock line profiling can cause great underestimates for soil designs and contract bidding purposes. Consequently, large contractual claims have been placed against the ministry because of inaccurate rock line profiling.

This practice was developed to provide information on the suitable techniques for evaluating the elevation of bedrock during the pre-contract engineering field investigation for new MTO highway construction. The intent of this practice is to provide a list of key steps for consideration during the design of a plan for rock line investigations for MTO work. Information is provided on field assessment, geological mapping, mechanical testing, subsurface investigation, weathered bedrock concerns, geophysics, tolerance recommendations, and terrain modeling and profiling.

A rock line evaluation was completed in a trial site area located south of North Bay, near South River and Sundridge. Much of this area is characterized by a surficial till unit containing numerous boulders with diameters exceeding 1.0 metre that mask the bedrock surface. A large power shovel excavator with capabilities of digging to depths of 7 metres was utilized to establish the rock line profile. In addition, an air track percussion drill was used to prove rock line in areas where the glacial drift exceeded the power shovel's digging limit. The air track was also capable of drilling through boulders to accurately establish the true rock line profile. Geophysical surveys were also carried out in the trial study area for comparison purposes.

In conclusion, this practice applies to commonly utilized geological and engineering techniques that are available for the determination of a rock line profile. By making this recommended practice available, the ministry expects that a more consistent and appropriate level of effort will be obtained on projects involving determination of rock line.

**Key Words** Boulders, field reconnaissance, geological mapping, geophysical surveys, GPS, karst, NFP, rock line, tolerances, weathered bedrock

**Distribution** Unlimited public distribution to technical audience

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Prepared by:
Robert G. Gorman, Chris A. Rogers
Materials Engineering and Research Office
Highway Standards Branch
Ontario Ministry of Transportation

1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

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# Executive Summary

The establishment of accurate rock line elevations for new highway construction has traditionally been a challenging task facing highway designers in many parts of the province. Inaccurate rock line profiling can cause great underestimates for soil designs and contract bidding purposes. Consequently, large contractual claims have been placed against the ministry due to inaccurate rock line profiling.

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# Introduction

The purpose of this practice is to provide information on the suitable techniques of evaluating the elevation of the bedrock (rock line or top of the bedrock surface) during the pre-contract engineering field investigation for Ministry of Transportation (MTO) highway construction. This practice has been primarily developed for new alignments as opposed to widening, earth to rock transition areas, or rock cut (ditching areas). Information is provided on field assessment, geological mapping, mechanical testing, subsurface investigation, geophysics, and terrain modelling. The nature and scope of a rock elevation investigation must reflect the specific characteristics of each individual situation. It is impractical to provide a practice that covers every possible rock elevation situation for all sites and impractical to determine the rock elevation everywhere. Consequently, the practices described in this document may need to be modified to reflect a lesser or greater degree of fieldwork activity to best suit the actual site conditions that are encountered and the degree of accuracy required.

This practice should be read in conjunction with, and should not supersede, the guidelines for Soils and Pavement Investigations.

This practice establishes the basic minimum requirements for consultants engaged in this type of evaluation for rock line determination. It is imperative, however, that a properly trained and experienced specialist be involved with the determination of rock line. The qualifications for a specialist include:

- A licensed professional engineer with a minimum of five years related experience in rock mechanics, geotechnical, or geological engineering, or
- A licensed geoscientist with a minimum of five years related experience in engineering geology or geophysics.

In addition to the qualifications above:

- Field investigation work must be carried out under the direction of a licensed professional engineer or geoscientist; and
- Field investigations may be undertaken by competent junior staff with engineering geology, geological engineering, or geological/geophysical expertise.

The intent of this practice is to provide a list of key steps for consideration during the design of a plan for rock line investigations for MTO work.

# Relevant Documents

## PROFESSIONAL ENGINEERS

Professional Engineers Providing Geotechnical Engineering Services Guideline, Professional Engineers Ontario, published by the Association of Professional Engineers of Ontario, 8p., 1993 (see http://www.peo.on.ca).

## AASHTO SPECIFICATIONS

R 13-99, Conducting Geotechnical Subsurface Investigations, Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1 - Specifications (see http://www.aashto.org/).

T 225-83 (1996), Diamond Core Drilling for Site Investigation, Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1 - Specifications.

Manual on Subsurface Investigations, American Association of State Highway and Transportation Officials, Washington, DC, 1987.

## ASTM STANDARDS

D420, Guide to Site Characterization for Engineering Design and Construction Purposes, Annual Book of ASTM Standards, Volume 04.08 (see http://www.astm.org/).

D2113, Practice for Rock Core Drilling and Sampling of Rock for Site Investigation, Annual Book of ASTM Standards, Volume 04.08.

D3740, Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as used in Engineering Design and Construction, Annual Book of ASTM Standards, Volume 04.08.

D4879, Practice Guide for Geotechnical Mapping of Large Underground Openings in Rock, Annual Book of ASTM Standards, Volume 04.08.

D5079, Practice for Preserving and Transporting Rock Core Samples, Annual Book of ASTM Standards, Volume 04.08.

D5434, Guide for Field Logging of Subsurface Explorations of Soil and Rock, Annual Book of ASTM Standards, Volume 04.08.

D5518, Guide for Acquisition of File Aerial Photography and Imagery for Establishing Historic Site - Use and Surficial Conditions, Annual Book of ASTM Standards, Volume 04.08.

D5730, Guide for Site Characteristics for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Ground Water, Annual Book of ASTM Standards, Volume 04.09.

D5777, Guide for Using the Seismic Refraction Method for Subsurface Investigation, Annual Book of ASTM Standards, Volume 04.09.

D5782, Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water - Quality Monitoring Devices, Annual Book of ASTM Standards, Volume 04.09.

D5878, Guide for Using Rock Mass Classification Systems for Engineering Purposes, Annual Book of ASTM Standards, Volume 04.09.

D6032, Test Method for Determining Rock Quality Designation (RQD) of Rock Core, Annual Book of ASTM Standards, Volume 04.09.

D6169, Guide for Selection of Soil and Rock Sampling Devices Used with Drill Rigs for Environmental Investigations, Annual Book of ASTM Standards, Volume 04.09.

D6429, Guide for Selecting Surface Geophysical Methods, Annual Book of ASTM Standards, Volume 04.09.

D6430, Guide for Using the Gravity Method for Subsurface Investigation, Annual Book of ASTM Standards, Volume 04.08.

D6431, Guide for Using the Direct Current Resistivity Method for Subsurface Investigation, Annual Book of ASTM Standards, Volume 04.08.

D6432, Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation, Annual Book of ASTM Standards, Volume 04.09.

## MINISTRY OF TRANSPORTATION

MTO Laboratory Testing Manual, Rev. 24, December 2007, published by Materials Engineering and Research Office, Highway Standards Branch, Ministry of Transportation, available online: https://www.raqsa.mto.gov.on.ca/login/raqs.nsf/English/Graphic/ViewQualifiedLaboratories?OpenForm.

Materials Engineering and Research Office, Standard Practice for Aggregate Resource Evaluation, 2002.

Surveys and Design Office, Pavement Design and Rehabilitation Manual, 1990.

Southwestern Region Geotechnical Section, Geotechnical Investigations and Pavement Design Report Guidelines for MTO, January 2002, p. 14.

Central Region Geotechnical Engineering Section, Central Region Pavement and Soils Field Investigation Guidelines, June 1999, Version 2.0, p. 12.

Eastern Region Geotechnical Section, Geotechnical Investigation and Pavement Design Report Guidelines, August 2000, p. 19.

Northern Region Geotechnical Section, Northern Region Pavement Design Practices and Guidelines, May 1997, p. 54.

Northwestern Region Geotechnical Section, Northwestern Region Geotechnical Investigation Minimum Requirements, June 1998, p. 17.

Ministry of Transportation and Communications, Engineering Materials Office, Materials Information Report MI-47, Guide to the Description of Rock for Engineering Purposes, 16p., 1982.

Ministry of Transportation and Communications, Development of Remote Sensing-Based Procedure to Estimate Boulder Concentrations, Research and Development Branch, MTC Report Number Special Publication SP-019, 34p., 1984.

Ontario Provincial Standards for Roads and Municipal Services, Volumes 1, 2, and 3, Ministry of Transportation, in conjunction with Municipal Engineers Association and Ministry of the Environmental, distributed by Ronen Publishing House Inc.

## MISCELLANEOUS

Canadian Foundation Engineering Manual, Third Edition, Canadian Geotechnical Society, Technical Committee on Foundations, 1992, pp.512.

Ministry of the Environment of Ontario, Water Resources Act, R.R.O. 1990, Regulation 903, Amended to O.Reg. 128/03, p. 16.

The Occupational Health and Safety Act, and Regulations for Construction Projects, 1991, Ontario Regulation 213/91, Ontario Ministry of Labour, Queen's Printer for Ontario, distributed by Publications Ontario Bookstore (see http://www.gov.on.ca/lab/main.htm).

# Definitions

Aerial Photographs: a photograph of the earth's surface taken from the air. It is usually one of a series taken from an aircraft moving in a systematic pattern at a given altitude in order to obtain a mosaic for mapping land divisions, geology, soil, vegetation, topography, etc.

Attitude: the position of a structural surface relative to the horizontal, expressed quantitatively by both strike and dip measurements.

Bedding Surface: a surface, usually conspicuous, within a mass of stratified rock, representing an original surface of deposition.

Bedrock: the solid rock that underlies gravel, soil, or other superficial material.

Boulder: a detached rock mass with an average dimension larger than 200 mm.

Brunton Compass: a compact pocket instrument that consists of an ordinary compass, folding open sights, a mirror, and a rectangular spirit-level clinometer. It can be used in the hand or on a staff or light rod for reading horizontal and vertical angles, for levelling, and for reading the magnetic bearing of a line. It is used in sketching mine workings, and in preliminary topographic and geologic surveys on the surface. Usually called a "Brunton". Synonym: *pocket transit* (see http://www.brunton.com/).

Carbonate Rock: a rock consisting chiefly of carbonate minerals such as limestone, dolostone, or carbonatite; specifically, a sedimentary rock composed of more than 50% by weight of carbonate minerals.

Casing: heavy metal pipe, lowered into a borehole during drilling and cemented into place. It prevents the sides of the hole from caving, prevents loss of drilling mud or other fluids into porous formations, and prevents unwanted fluids from entering the hole.

Clastic Rock: a consolidated sedimentary rock composed principally of broken fragments derived from pre-existing rocks of any origin or from solid products formed during chemical weathering of such rocks that have been transported mechanically to their places of deposition, e.g. a sandstone, conglomerate, or shale, or a limestone consisting of particles derived from a pre-existing limestone.

Cross Bed: a single bed, inclined at an angle to the main planes of stratification.

Dike: a tabular igneous intrusion that cuts across the planar structure of the adjacent host rocks a discordant, usually wall-like rock mass that may extend many kilometres across country, usually following vertical or near-vertical discontinuities in the host rocks.

Dip: the angle that a stratum or any planar feature makes with the horizontal, measured perpendicular to the strike and in the vertical plane.

Discontinuity: a surface of separation in the earth materials that may be filled with other materials.

Drill Rig: includes drilling machine, mast or derrick, circulating pumps, and mounting platform.

Drill Rod: hollow steel tubes connected to the drill bit or core barrel and to the rotary head of the drilling machine.

Drilling: the act or process of making a circular hole with a drill or other cutting tool for the purpose of blasting, exploration, prospecting, validation, or obtaining oil, gas, or water, etc.

Electrical Conductivity: a measure of the ease with which a conduction current can be caused to flow through a material under the influence of an applied electric field. It is the reciprocal of resistivity and is measured in mohs per metre.

Electrical Resistivity: the electrical resistance per unit length of a unit cross-sectional area of a material. It is measured in ohms.

Evaporite Rock: a non-clastic sedimentary rock composed primarily of minerals produced from a saline solution as a result of extensive or total evaporation of the solvent. Examples include gypsum, anhydrite, rock salt, primary dolomite, and various nitrates and borates.

Existing Rock Surface: the exposed rock surface or the rock surface after removal of overburden.

Fault: a surface, or closely spaced surfaces, of rock fracture along which there has been displacement, which may range from a few millimetres to many kilometres. A fault plane is the same as a fault surface and is normally more or less planar.

Field Reconnaissance: normally carried out by a specialist that makes first-hand observations and collects both surface and subsurface data from the field.

Foliation: the planar arrangement of textural or structural features in any type of rock, for example, the schistosity in a metamorphic rock.

Geophysics: the study of the physical characteristics of the earth by means of instruments and methods to determine subsurface conditions by analysis of such physical properties as specific gravity, electrical conductivity, magnetic susceptibility, radioactivity, seismic wave propagation, heat flow, etc.

GPS: the Global Positioning System is a constellation of navigation satellites that orbit the earth. The precise time and position information transmitted by these satellites is used by a GPS receiver to compute a position fix.

Gypsum: hydrous calcium sulphate associated with other evaporite minerals in extensive beds interstratified with limestones, shales, and clays.

Joint: a natural break in physically continuous rock with little or no displacement parallel to the surface.

Karst: a type of topography formed in limestone, gypsum, and other rocks by dissolution, characterized by sinkholes, caves, and underground drainage.

Mineral: (i) a naturally formed chemical element or compound normally having a characteristic crystal form and a definite composition, (ii) a mass of naturally occurring mineral material (such as metallic ores and aggregate minerals) which is judged, against arbitrary physical, chemical, and economic criteria, to have foreseeable use.

Outcrop: the total area over which a particular rock unit or structure is exposed at the ground surface.

Palaeozoic: an era of geological time, from the end of the Precambrian to the beginning of the Mesozoic, or from about 570 to about 225 million years ago and, in Ontario, includes Ordovician, Silurian, and Devonian age rocks.

Photogeology: geological studies based entirely on examination of aerial photographs.

Pleistocene: the earliest epoch of the Quaternary Period during which the Ice Ages occurred. Spans the period between two million and ten thousand years ago.

Precambrian: that period of time (approximately 4000 million years) from the consolidation of the earth's crust to the beginning of the Palaeozoic era, and the corresponding system of igneous and metamorphic rocks.

Quaternary: the latest era of geological time, from two million years before the present, extending to the present time.

Rock: natural beds or massive fragments of the hard, stable, cemented part of the earth's crust, igneous, metamorphic, or sedimentary in origin, which may be weathered and/or unweathered, and includes boulders having a volume of $1 m^3$ or greater.

Rock Elevation: elevation of the rock line or top of the bedrock surface.

Rock Head: top-of-rock (British usage).

Rock Line: elevation of the top of the unexposed bedrock or outcrop surface.

RQD: Rock Quality Designation, the total length of those pieces of sound core that are 10 cm or greater in length in a core run expressed as a percentage of the total length of that core run.

Sedimentary Rock: a rock resulting from the consolidation of loose sediment that has accumulated in layers (most commonly under water), or a chemical rock formed by precipitation, or an organic rock consisting largely of the remains of plants and animals.

Shale: a fine-grained, low-strength, sedimentary rock that undergoes rapid deterioration upon exposure.

Slaking: the crumbling and disintegration of shales and similar clay-bearing rocks upon exposure to cycles of wetting and drying.

Strike: the direction or trend taken by a discontinuity surface, e.g. joint, bedding plane, fault, etc., as it intersects the horizontal.

Subcrop: the unconformable truncation of one stratigraphic unit against another below ground.

Swamp: an area of low, waterlogged ground having shrubs and trees, with or without the formation of peat.

Top-of-Rock: top of bedrock surface.

Total Station: an electronic instrument that contains an electronic theodolite and electronic distance meter.

Unconformity: a substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as an interruption in the continuity of a depositional sequence of sedimentary rocks or a break between eroded igneous rocks and overlying younger sedimentary strata.

Weathering: a comprehensive term for all of the processes by which rock and soil are altered under the direct influence of the hydrosphere and atmosphere.

# Preliminary Office Investigation

## BACKGROUND LITERATURE SEARCH FOR ROCK LINE INVESTIGATION

A thorough literature search on relevant available information on subsurface conditions is paramount for any rock line investigation. Table 1 is a summary of sources of background information for site-specific geological information (also see Appendix A).

Published information could shed light on subsurface conditions including both recent and old topographic maps, surficial and bedrock mapping, southern and northern Ontario geological highway maps, drift thickness maps, mine records, county soil mapping, water well records, and provincial and private sector geology, and subsurface exploration reports. Previous MTO contract information, including information pertaining to subsurface rock in existing roadways and right-of-ways, should be evaluated. Background information for site investigations can be obtained from various federal and provincial government sources. Specific addresses of the various agencies are located in Appendix A. Private agencies and consultants also may be able to supply subsurface information in report format. Additional information may be available from alternate sources that have not been identified in Table 1.

| Information Sources | Provincial Government | Federal Government | Comments |
|---|---|---|---|
| Topographic Maps and Surveys | Ministry of Natural Resources<br><br>Prov. Scales: 1:2,000, 1:10,000,1:20,000, 1:100,000, 1:126,720, and 1:600,000 | Canada Map Office<br>(see http://www.maps.nrcan.gc.ca/cmo/)<br>Fed. Scales: 1:25,000, 1:50, 000, 1:125,000, 1:25,000, 1:500,000, and 1:1,000,000 | Shows elevation contours.<br><br>Complete coverage at all scales is not available. |
| Aerial Photographs | Ontario Ministry of Natural Resources<br>Prov. Scale: 1:15,000 | National Air Photo Library<br>(see http://www.irphotos.nrcan.gc.ca/)<br>Fed. Scale: 1:50,000 | Shows surficial features.<br><br>MTO also has extensive coverage. |
| Satellite and Unusual Imagery | Ontario Ministry of Natural Resources<br>(see http://www.mnr.gov.on.ca/) | Canada Centre for Remote Sensing<br>(see http://www.ccrs.nrcan.gc.ca/) | Shows large scale surficial features. |
| Soil Surveys | Ontario Ministry of Agriculture and Food<br>Scales: 1 63,360, 1:50,000, and 1:20,000<br>(see http://www.gov.on.ca/OMAFRA) | - | Shows distribution of soil types to a depth of 1 metre. |
| Mine Records | Ontario Ministry of Northern Development and Mines<br>(see http://www.mndm.gov.on.ca/) | - | Shows location of active and old mines.<br><br>Important to use this information in some parts of Ontario. |
| Seismicity & Geophysics Data | Ontario Ministry of Northern Development and Mines<br>(see http://www.mndm.gov.on.ca/) | Geological Survey of Canada<br>Energy, Mines and Resources<br>(see http://www.agc www.bio.ns.ca/) | Shows results of geophysical surveys.<br>Generally at rational scales. |
| Water Well Information | Ontario Ministry of Environment<br>(see http://www.ene.gov.on.ca/) | Canmet<br>(see http://www.ccrs.nrcan.gc.ca/) | Shows locations and subsurface materials, as well as depth of water wells. |

**Table 1 Information Sources**

## Table 1 – Cont'd.

| Information Sources | Provincial Government | Federal Government | Comments |
|---|---|---|---|
| Geological Maps & Information | Ontario Geological Survey:<br>• Summary of field work and other activities<br>• Miscellaneous papers<br>• Resident geologists reports | Geological Survey of Canada Index to publications:<br>• Memoirs<br>• Bulletins<br>• Papers<br>• Coloured maps<br>• Maps<br>• Open files | Geological reports and maps for N. and S. Ontario at various scales |
| | Ontario Geological Survey:<br>Miscellaneous Paper 77<br>Index to published reports and maps: | | |
| | • Precambrian Maps<br>For N. Ontario. Scale: Various | | Shows hard rock bedrock deposits throughout N. Ontario. Depth of overburden can be judged from shading on maps. |
| | • Palaeozoic Maps<br>For S. and some of N. Ontario. Scale: 1:50,000 | | Shows rock bedrock (limestone and dolostone) deposits throughout N. and S. Ontario. |
| | • Drift Thickness Maps<br>Mainly for S. Ontario. Scale: 1:50,000 | | Shows thicknesses of overburden that overlie Palaeozoic rocks. |
| | • Bedrock Topographic Maps<br>Mainly for S. Ontario. Scale: 1:50,000 | | Shows topography of bedrock deposits primarily in S. Ontario. |
| | • Quaternary Maps<br>For S. Ontario and selected areas of N. Ontario.<br>Scale: 1:50,000 | | Shows extent of surficial deposits. |
| | • Geophysical Maps<br>For all Ontario. Scale: 1:20,000 and 1:250,000 | | Shows geophysical information about surficial and bedrock deposits. |
| | • Aggregate Maps<br>For all S. Ontario and selected areas of N. Ontario.<br>Scale: 1:50,000 | | Shows extent of sand and gravel and bedrock deposits. |
| | • Northern Ontario Engineering Geology Terrain Studies (NOEGTS) mapping for areas north of Orillia, Ontario.<br>Scale: 1:100,000 | | Shows potential of surficial deposits and bedrock deposits throughout areas north of Orillia for engineering purposes. |
| | • Geological Compilation Series Maps<br>For N. Ontario. Scale: 1:253, 440 and 1:126,000 | | Shows general extent and potential for bedrock deposits and some surficial deposits in N. Ontario. |

**Table 1 – Cont'd.**

| Information Sources | Provincial Government | Federal Government | Comments |
|---|---|---|---|
| Geological Maps & Information | 1. Freeman, E.B., ed. 1979: Geological Highway Map, Southern Ontario; Ontario Geological Survey, Map 2441<br>2. Ontario Geological Survey, 1986: Geological Highway Map, Northern Ontario: Ontario Geological Survey, Map 2506 | - | Provincial Highway Geology Maps show soft and hard rock deposits throughout S. and N. Ontario. |
| | Ontario Geological Survey<br>Geology of Ontario:<br>• Quaternary maps<br>• Palaeozoic and Precambrian maps<br>• Tectonic Assemblages of Ontario maps | | Mapping available for all Ontario.<br>Scale 1:1,000,000 |
| | Ontario Geological Survey:<br>Physiography of Southern Ontario | | Quaternary mapping for S. Ontario. Scale: 1:600,000 |
| Geocres Foundation Files | Ontario Ministry of Transportation | - | Contains specific subsurface information on structure foundation depths. |
| Urban Geological Data Bank | Ontario Geological Survey | - | Shows location and subsurface materials encountered in geotechnical boreholes and bedrock elevations. |
| Mineral Aggregate Inventory Data Bank | Ontario Ministry of Transportation<br>Head Office and Regional Offices | - | Contains information on the depth of unconsolidated sediments for selected areas. |
| MTO Soils Profiles | Ontario Ministry of Transportation Regional Offices | | Contains information on the depth of unconsolidated sediments along existing highway alignments. |
| Other Sources of Subsurface Information | Ontario Universities | - | • Appropriate Consultant Reports and Maps<br>• Conference Proceedings<br>• Professional Journals<br>• Appropriate University Theses |

Published information could shed light on subsurface conditions including both recent and old topographic maps, surficial and bedrock mapping, southern and northern Ontario geological highway maps, drift thickness maps, mine records, county soil mapping, water well records, and provincial and private sector geology, and subsurface exploration reports. Previous MTO contract information, including information pertaining to subsurface rock in existing roadways and right-of-ways, should be evaluated. Background information for site investigations can be obtained from various federal and provincial government sources. Specific addresses of the various agencies are located in Appendix A. Private agencies and consultants also may be able to supply subsurface information in report format. Additional information may be available from alternate sources that have not been identified in Table 1.

## AERIAL PHOTOGRAPH INTERPRETATION AND GEOLOGICAL MAPPING

This section deals with the interpretation of vertical black and white panchromatic aerial photography (60% overlap) and other remote sensing data before the rock line investigator actually goes into the field (photogeology). The great value of examining the aerial photographs before going into the field is that the investigator can evaluate the surface of the study area, if need be, for an extended period of time. The photos can be used to gain an idea of the geologic features and accessibility of an area and, after the field visit, to aid in the compilation of geologic data on the final map. A photographic scale of between 1:10,000 and 1:15,840 is generally adequate for the identification of landforms. All interpretation should be completed by an investigator who is experienced and familiar with aerial photography and remote sensing interpretations.

The principles of aerial photograph interpretation are covered in a number of books and the rock line investigator is referred to works by: Avery (1968), Compton (1962), Goodman (1993), Leuder, (1959), Mollard (1962), and Piteau (1979). Stereoscopic study is an essential adjunct to geological mapping and should be utilized to the fullest extent. Generally, the cost of obtaining existing aerial photograph coverage for a study area is reasonable. Table 1 and Appendix A reveal sources where aerial photographs can be purchased. In addition, numerous private aerial mapping companies can produce recent project-specific aerial photographic coverage upon demand.

# Preliminary Field Investigation/Mapping

One of the initial tasks of the rock line investigator is to walk the entire length of the surveyed right-of-way, whether it has been cleared or not. This provides the investigator with a good perspective on the physiography of the study area.

The purpose of field reconnaissance is to obtain as much surface and subsurface information as possible without drilling exploratory boreholes. Field reconnaissance includes the identification of all surface geological conditions that have been identified and noted on the aerial photographs while in the office. All bedrock or overburden exposures and conditions that were not identified or mapped in the office should now be accounted for and documented on the aerial photographs or separate field maps. Field reconnaissance includes the mapping of stratigraphic exposures and bedrock structural characteristics.

During the reconnaissance, detailed field mapping should be carried out at scales ranging from 1:500 to 1:1000, including the use of a Brunton or other suitable compass to measure strike and dip of planar geologic structures such as bedding, faults, joints, and foliations. Detailed information on field reconnaissance and the mapping of stratigraphic exposures is available from published works including Compton (1962) and Goodman (1993).

During the field excursion, all existing bedrock outcrops and structural characteristics of the exposed bedrock including faults, fold belts, joints, foliation, layering, bedding planes, and sinkholes should be mapped where identified on the aerial photographs along the entire length of the proposed highway corridor.

If surface boulder concentrations are noted, their occurrences should also then be plotted on the photographs for later consideration. The position of outcrops that occur adjacent to the highway right-of-way should also be mapped, as the information they hold may become important later. Outcrop positions and their height can later be accurately measured by a conventional total station instrument.

In addition, certain Global Positioning Systems (GPS) equipped with survey grade receivers have the best potential to accurately measure outcrop positions. The various grades of GPS and their respective accuracy are portrayed in Table 2. It should be noted that GPS elevations may be related to an ideal geometric shape of the earth's surface (ellipsoid) rather than benchmark elevations that are normally utilized on MTO projects. This could result in differences of several metres unless properly accounted for. If GPS is to be used for accurate plotting, the appropriate vertical and horizontal datums and mapping grid projection should be utilized.

**Table 2 GPS Types and Accuracy Levels**

| | | | |
|---|---|---|---|
| Cheapest hand-held units for hunting, hiking, etc. $300.00 | Hand-held with correction signals WWAS or CDGPS<br><br>Wide Area Augmentation System or Canada's Differential Global Positioning Systems | Vertical accuracies within double the horizontal<br><br>Vertical with WAAS | Survey grade with backpack or fully contained on hand-held pole $30,000.00 |
| **Accuracy Level**<br>10-15m (horizontal) | **Accuracy Level**<br>1.5m (horizontal) | **Accuracy Level**<br>3m (vertical) | **Accuracy Level**<br>0.01m |

Satellite and aircraft spectral mapping tools (handset) may provide information on significant geological structures that may be indicative of faults and fractures.

In addition, all human features such as rail lines, gas lines, hydro corridors, homes, farms, water well locations, and swamps should ideally be marked on the photographs before field work commences. With appropriate investigation, these may all yield information about depth to bedrock. It is important that the geotechnical rock line investigator allows the MTO Regional Geotechnical Section access to all of the aerial photographs on which is shown all observable information if requested.

# Geophysical Surveys

This section deals with on-site investigation of the ground surface and subsurface by geophysical surveys. Geophysical methods have proven to be a valuable adjunct to geological mapping and drilling. Depending on the nature of the terrain within the project area and available funding, geophysical surveys are optional and should be utilized where appropriate. Geophysical methodology generally serves well to tie in subsurface information between control points such as drill holes and known outcrops. Because geophysical methods can have a wide margin of error in interpretation, geophysical information must be verified at discrete intervals by borings or other direct methods of subsurface exploration.

The decision to use geophysical surveys should depend on economic and reliability criteria. For instance, geophysics is unlikely to be economic if reliable information can be cheaply obtained by other means. An example would be thin overburden on flat-lying bedrock where hand augers or use of an excavator may give reliable data at low cost. Geophysics may well be a useful tool in areas of substantial overburden where access for power equipment such as percussion drills is difficult and the amount of drilling must be limited.

Geophysical methods do not actually provide geological data but merely record changes that occur when some form of energy passes through the materials under study. The choice of geophysical method depends on whether there is a physical property contrast between the bedrock and the overlying material. Top-of-rock may be difficult to determine if the bedrock surface is weathered or highly fractured. Highly irregular rock surfaces may present additional profiling difficulties.

Table 3 represents eight methods of commonly used geophysical techniques. The geophysical methods should be carefully selected and results interpreted by a skilled experienced specialist with the specific site conditions in mind. It is recommended that the surveys be carried out perpendicular to the right-of-way at regular longitudinal intervals so that the entire width of potential grading area will be covered.

To obtain detailed information about the geophysical methods outlined in Table 3, the rock line investigator should refer to the following work: Goodman, (1993), Kearey & Brooks (1991), Milsom (1989), Smith (1999), and Smith & Collis (1993).

**Table 3 Geophysical Survey Methods for Depth to Bedrock Determinations**

| Method | Measured Parameter | Operative Physical Property | Primary or Secondary Choice of Method |
|---|---|---|---|
| Seismic | Travel times of reflected/refracted seismic waves | Density and elastic moduli | P |
| Gravity | Spatial variations in the strength of the earth's gravitational field | Density | S |
| Magnetics | Spatial variations in the strength of the magnetic field | Magnetic susceptibility and remanence | S |
| Electrical: Resistivity | Earth resistance | Electrical conductivity | S |
| Electrical: Induced Polarization | Polarization voltages | Electrical capacitance | S |
| Electrical: Self Potential | Electrical potentials | Electrical conductivity | S |
| Electromagnetic | Response to electromagnetic radiation | Electrical conductivity and inductance | S |
| Radar | Time travels of reflected radar pulses | Dielectric constant | P[3] |

**Note**:
1. Adapted and modified from Kearey & Brooks, 1991, and ASTM D6429-99.
2. "P" implies primary method of choice. "S" implies secondary choice or alternate method.
3. Shallow depth only.

Of all of the geophysical methods listed in Table 3, the seismic and electrical resistivity methods have both proven to be useful means of obtaining subsurface information and as economical supplements to borings in rock line profile determination.

Resistivity or its opposite, conductivity, is measured by passing a current between electrodes that have been placed into the ground. The electrical resistivity method of subsurface exploration is based on the fact that different materials offer varying resistances to the passage of an electric current. Several methods involving different electrode arrangements have been developed for making field resistivity assessments. Two main types of resistivity surveys are utilized for sub-surface explorations, namely, electric profiling and soundness. Electric profiling provides information concerning lateral variations in subsurface materials. The purpose of electric sounding is to provide information on the variation of subsurface materials as depth increases. Electric sounding has been a proven methodology to estimate the depth to the top-of-rock and obtain rock profiles. The values obtained by the sounding method are strongly influenced by near-surface irregularities including ore bodies and other materials by affecting the electric field. Advantages of this method include a low-cost, economical means of exploration, excellent portability, and rapid testing. However, it is not as accurate or reliable as the seismic method.

Seismic methods of exploration are based on the fact that shock waves travel at different velocities through different types of materials (Lowe and Zaccheo, 1975). The speed at which shock waves are generated from a natural or man-made source (heavy hammer or explosive charge) and travel through materials is determined by the nature of the materials they pass through. The shock generates three types of waves, namely, compression, shear, and surface, and it is only the compression that is observed. These waves are classified as: direct, reflected, or refracted.

Both refraction and reflection seismic methods have been successfully utilized for the determination of the rock line position along with the overlying layers. In addition, these methods have traditionally been utilized to locate and characterize geologic structure. Figure 1 shows a seismic line being strung out prior to evaluating the bedrock profile south of North Bay.

**Figure 1 Seismic Profiling for Bedrock Line Evaluation South of North Bay**

Seismic refraction generates acoustic energy waves that map the changes in the density and the elasticity of the material they pass through. Seismic has higher resolution than radar and is attenuated by resistive media (dry sands and gravels).

Ground Penetrating Radar (GPR), similar to seismic refraction measurements, relies on the transmission of a pulse of energy into the ground. In this case, the energy is in the form of high-frequency electromagnetic waves. GPR measures changes in the dielectric properties of the material through which the waves pass. GPR has extremely high resolution, but the energy of the signal is reduced when it passes through conductive materials. Environments not conducive to using the radar method include high conductivity soils such as clays and sediments saturated with salt water. In general, radar can be more accurate than seismic, but seismic is better in varying soil conditions. The

cost of radar can be expensive when compared to other methods. Figure 2 shows a GPR survey being carried out to determine subsurface conditions south of North Bay.

**Figure 2 GPR Survey Being Carried Out for Bedrock Line Determination**

# Planning for Power Equipment Subsurface Investigation

Planning for a power equipment investigation would follow after the initial field reconnaissance has been completed. All surface geological conditions should be noted and identified on the aerial photographs or on large-scale field maps. When all of this field information has been assessed, including the subsurface information gathered from existing sources, the specialist should have an initial idea where the probable rock line exists along the length of the study area.

Where available rock line field data are lacking, and no outcrop is exposed, additional subsurface information must be obtained. These methods include the use of hand auger borings, test trenching, hand test pitting, backhoe excavating, hollow stem augering, Air Track (Percussion) drilling, or diamond core drilling (see Table 4).

Each MTO region provides geotechnical consultants with individual guidelines for pavement and field investigations. The purpose of a pavement field investigation is to obtain factual information pertaining to rock necessary to effectively assess subsurface conditions. A rock line specialist should refer to the individual regional guidelines when preparing a layout plan for subsurface explorations. It is necessary for the specialist to generate the rock line profile during the on-site investigation on a section-by-section basis. The directness and immediacy of interpretation eliminates confusion that can arise when one attempts to interpret subsurface data later in the office. The rock line should be generated in real time by the specialist doing the investigation and who is responsible for delivering the profile, thus discouraging ambiguity. The generation of the rock line profile on site allows for the synthesis of all available clues to the location of the rock line. This on-site approach encourages getting sufficient field information to develop the rock line with a high level of confidence.

Another advantage of generating the rock line in real time includes the flexibility of undertaking secondary boreholes at selected locations. Secondary holes can also assist in the investigation of anomalous geological features including weathered bedrock, karst topography, and fault zones. The positions of all primary or secondary boreholes should be clearly identified by manual measurement of station and offset using field alignment staking, total station surveying, or by GPS if equipped with survey quality receivers.

On occasion, the rock line specialist may be faced with a geologically complicated irregular bedrock surface (i.e. karst topography), or a significant bedrock valley with deep and irregular overburden. This complicated bedrock surface may not have been identified by use of the traditional subsurface investigation techniques. In these cases, consultation with MTO should occur to determine the most appropriate approach.

The rock line specialist should look not only at the specific site but also at adjacent sites of bedrock exposure for possible karst development.

# Rock Line Subsurface Investigation

The completion of the subsurface investigation to determine the rock line profile depends on various factors, including the type of subsurface material overlying the top-of-rock, depth of exploration to rock line, and nature of terrain. The type of techniques and equipment commonly utilized to establish the rock line profile is summarized in Table 4.

**Table 4 Equipment Type Commonly Used for Rock Line Investigation**

| Equipment | Depth Potential | Overburden Type | 2004 Approx. Cost $ |
|---|---|---|---|
| Hand Augers, Hole Diggers, Shovels, Picks | -3 m | Soils | 10/m |
| Earth Excavation Equipment, Shovel Excavators (including operator) | 1-7m or potentially more | Soils | 195/hr |
| Hollow Stem Augers (including driller) | 50m (sand/gravel) more than 50m in clays | Soils | 30-50/m |
| Rotary Core Drilling Triple Tube Core Water | Unlimited | Weathered/Fractured Rock | 30-50/m |
| Rotary Core Drilling Double Tube Core Barrels Water or Air Flush | Unlimited | Rock | 30-50/m |
| Air Track (Percussion) Drilling (including driller, assuming clear right-of-way) | Unlimited Varies with rock type | Soil or Rock | 20-60/m |
| Rotary Tricone Drilling Water or Air to Flush Rock Cuttings | Unlimited Varies with rock type | Soil or Rock | 30-50/m |

Regardless of what method of drilling is utilized to ascertain the rock line profile, it is strongly recommended that an experienced drilling contractor be on site. It is particularly important that a qualified trained professional is on site to assess the nature of the drilling chippings (powder) or rock cores (including percent core recovery and RQD) as they are discharged from the borehole. NX or BX core sizes are the most optimal sizes for general rock engineering purposes.

A trained professional normally utilizes a hand lens to evaluate the nature and petrography of the chippings and rock cores. Identification of rock type will assist in determining whether or not true bedrock has been encountered. For example, this method can determine if the chippings are from an imported boulder or float slab overlying and masking the true bedrock that underlies the area.

Table 5 provides a summary of commonly used and available subsurface exploration equipment types and approximate drilling speed rates. Costs of subsurface exploration would respectively increase when problems are encountered, i.e. downtime for mechanical breakdown, unexpectedly difficult ground conditions, additional mobilization, and poor weaker bedrock conditions.

**Table 5 Basic Equipment Types and Drilling Speed Rates**

| Equipment Type | Metres Per Hour |
|---|---|
| Earth Excavation Equipment<br>- Large Front Power Shovel Excavator | 5 in boulder tills<br>10 in soils, sandy tills |
| Track Mounted Hollow Stem Auger | 2-3 in soils, slower if boulders are encountered includes drilling, sampling, and testing |
| Air Track (Percussion) Drilling | 45 in soils, sandy tills<br>18 in Precambrian rock |
| Diamond Drilling<br>**Note**: To confirm rock quality and investigate that the true rock line has been established, NX/NQ core is required. | 1-3 in rock<br>includes coring and sampling (varies with rock type) |

The type of subsurface investigation method used to establish the rock line profile depends upon the information gathered during the field mapping reconnaissance. If a geophysical survey method has been undertaken, the specialist should also then tie in the findings to the reconnaissance information before making their final choice of subsurface equipment. The borehole information will then either verify or disprove the initial rock line geological profile originally developed during the early stages of the evaluation.

At this point, if there are any uncertainties in the interpretation of the geophysical survey data, or if surface outcrops or borehole information suggest the presence of an irregular bedrock surface, additional boreholes should be advanced at these locations. It may also be necessary for the rock line investigator to utilize more than one type of subsurface exploration equipment in order to prove rock line. Additional subsurface information will improve and complement the overall overview of the rock line study and provide better correlation between the borings and location of the rock line.

Explorations shall be constructed, maintained, and abandoned, or otherwise restored, to ensure the safety and environmental integrity of the site (MOE Water Resources Act, R.R.O.1990, Regulation 903 and its Amendments). Test pits shall be backfilled with excavated material in reverse order of extraction and re-vegetated or otherwise protected from erosion. Temporary open holes shall be adequately covered. Holes in roads shall be backfilled as required to prevent future settlement and acceptably patched where pavement surfaces have been damaged.

# Weathered Bedrock Surface Assessment and Rock Line Profiling Concerns

The presence of weathered bedrock surfaces represents true challenges to specialists who are responsible for establishing the rock line profile. Care has to be taken when subsurface investigation is carried out through overburden to the bedrock surface to ensure that intact bedrock has, in fact, been encountered.

Shale is a common clastic sedimentary rock found in Ontario that can cause misinterpretation problems for rock line investigators. Shale can range in consistency from very soft deeply weathered material to hard, unweathered strata. When shale is exposed to cycles of wetting and drying, it undergoes rapid deterioration by a slaking process. As a result of this slaking process, weathered shales are quite often difficult to distinguish from overlying clay, especially when the specialist is determining the rock line profile. A useful technique that may be employed with shales is the slake durability test (Rogers, EM-6, 1977). Testing of unweathered shale from adjacent locations will establish a base value to compare against materials suspected to be bedrock. Weathered materials and overlying clays will normally have much higher slake durability values and characteristics of the unweathered bedrock.

Establishing rock line within Palaeozoic limestones and dolostones and metamorphic marbles within Ontario can also be a challenge. Some of these rock types are subject to high rates of solution weathering by ground water. Consequently, the bedrock surface may become irregular, and may contain solution honeycombs, caves, and sinkholes. This type of landscape is known as karst, and is normally characterized by an extremely irregular surface on the top-of-rock.

This type of solution weathering is commonly found in limestones that exist between Coldwater (near Georgian Bay) and Warsaw (eastern Ontario), but also in other areas of Ontario such as James Bay Lowlands (Palaeozoic) and Lanark/Perth (Precambrian). Extreme caution must be exercised when investigators are establishing rock line in uneven solution-weathered carbonate rock, especially when covered by unconsolidated deposits.

In areas underlain by karst-affected carbonate rock that has significant overburden or is under water, it is often useful to examine the type and amount of karst development in adjacent outcrop areas. This information can then be extrapolated to the area under study and adjustments made to the proposed exploration program.

Evaporite rocks include gypsum, anhydrite, halite, and other less abundant saline units that occur among sedimentary rocks. Evaporite rocks include those of the Salina Formation in the Caledonia-Hagersville area. Solution cavities have been reported in evaporite rocks in central and southwestern Ontario. Similar obstacles exist in rock line determination with evaporite rocks as with solution-weathered limestone.

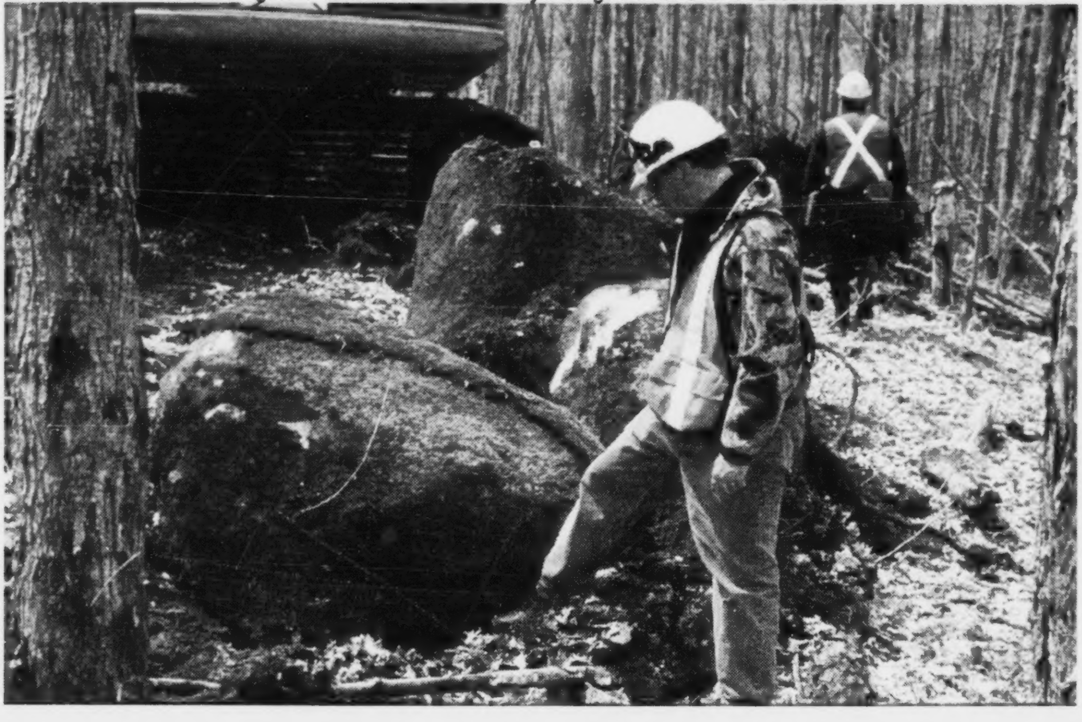
Geological conditions can exist where augers may encounter boulders, cemented gravel bodies, or floating rock slabs present in till and/or glacial deposits that overlie the bedrock surface. This can create a real challenge for the rock line investigator to determine where the position of the true bedrock surface actually is. Figure 3 shows the type of shovel excavator that can be utilized for subsurface exploration in areas where access may be restrictive because of thick vegetative cover. The advantage of this type of tracked machine is that it can clear its own path, and the shovel is capable of extracting large boulders (1-2m$^3$) that may overlay the bedrock surface.

**Figure 3 General View of a Large Power Shovel Excavator Evaluating Subsurface Conditions**


Test pitting by use of a power shovel excavator will usually cause severe landscape destruction and alteration. Figure 4 illustrates the damaged caused by a large power excavator consisting of trees pushed down and deep ruts in the ground. The size of the boulders is illustrated in this figure and in Figure 5 where these boulders were masking the bedrock surface in this particular area.

Figure 4 Damage Caused by a Large Power Shovel Excavator

Figure 5 Boulders Excavated by a Large Power Shovel Excavator



This type of subsurface investigation should not be done on privately owned land without the landowner being fully aware of the likely disturbance, particularly in wooded areas. In this case, the property should be restored to as near-original conditions as practical.

It is prudent for the specialist to have a sound knowledge of the surficial materials that overlay the bedrock surface before the subsurface investigation is initiated. If a bouldery till has been noted on a surficial geology map of the study area, or if surface boulder concentrations have been identified on the aerial photographs, there is then a strong potential that boulders may be encountered within the materials that overlay the bedrock surface. It should be noted that large contractual claims have arisen because inaccurate boulder contents have caused great under-estimates for soil designs and contract bidding purposes (Bird and Hale Limited, 1984). Bedrock maps should also be reviewed to determine whether there is any suggestion of bedrock integrity concerns that may affect rock line determination. Boulder contents (%) within overburden should be estimated and documented at the time of site investigation, for each cut or cut portions.

A review of drillers' logs can often indicate information such as No Further Penetration (NFP) due to the presence of boulders. If not addressed by subsequent deeper explorations using power shovel excavation or percussion drilling, this ambiguous data leaves the highway designer with the task of interpreting exactly where the bedrock surface is located. They normally do this in the office months after the subsurface investigation has been completed. To further complicate the process, there can be little or no verification/interpretation from the personnel who collected the data during the field investigation.

The incomplete or inappropriately interpreted data may be entered into a highway design software program and, consequently, an inaccurate rock line profile may be generated. Because of these types of interpretation problems, rock line profiles should be generated at the time of investigation.

When a rock line investigator has encountered floating rock slabs and boulders masking the true bedrock surface, it may be necessary to penetrate to as much as 3 metres into bedrock to confirm top-of-rock. It should not be necessary to do this at every location and obviously cannot be done with an excavator. During rock core examination, it is useful to examine the attitude of the layers in the recovered rock (diamond drilling only). This method may prove that the true bedrock surface has not been encountered when compared to the attitude of the bedrock locally exposed in nearby outcrops. In certain cases, such as investigating shales and solution-weathered bedrock, a 3-metre drilling depth may not be adequate. Expert geological knowledge of the general area would certainly benefit in any rock line profiling exercise.

As already mentioned, the presence of large boulders and boulder fields (see Figures 4 and 5) that overlay the true bedrock surface also has the potential to cause inaccurate rock line profiling. When the rock line specialist suspects that augers have encountered large boulders with NFP, the augers should be replaced with power shovel excavator or air track (percussion) drilling equipment as depicted in Figure 6 in order to establish the rock line profile.

Figure 6 Gardner-Denver Hydro Track Hydraulic Air Track
Establishing Rock Line in a Boulder Field South of Sundridge, Spring 2004

# Trial Study Site Area

During the late winter and spring of 2004, Northeastern Region sponsored additional work to complete a study on establishing the rock line for the four-laning work on Hwy. 11, south of North Bay near South River and Sundridge. The work initially involved an assessment of the area by collecting published information and studying aerial photographs and mapping all geological features, followed by a traverse along much of the staked realignment to complete the initial field reconnaissance.

A large power shovel excavator with capabilities of digging to depths of 7 metres was initially used to establish the rock line profile (see Figure 3). This machine was ideally suited to handle large boulders with diameters exceeding 1.0 metre that were common in this till unit. In areas where the glacial drift exceeded the power shovels limit of digging (i.e. 7 metres), an air track percussion drill was utilized (see Figure 6). This drill was tested at some of the same stations that the power shovel encountered bedrock and very similar rock line depth information was generated. At one particular station, the air track encountered a large boulder at a depth of 1.5 metres. If a traditional hollow stem auger had been used, it is probable that NFP would have resulted. The air track was able to quickly drill through the boulder and penetrate more than 13 metres through a sandy till unit to bedrock. This was an excellent example of how the potential of this machine can be utilized to accurately establish the true rock line. Because the depth of investigation when dealing with boulders can be variable, every effort must be made by the rock line specialist to be satisfied that true bedrock has been encountered.

In extremely complicated geological environments, it may be necessary to carry out specialized laboratory testing in order to establish a rock line profile. In a situation where access to the ground level is restricted, the drill chippings may then have to be evaluated under a hand lens, microscope, or by x-ray diffraction to determine whether true bedrock has been encountered. Only a person with a strong background in petrography should do this type of specialized evaluation.

Geophysical investigations were completed in the South River and Sundridge areas in order to establish the rock line for the four-laning work on Hwy.11. Both seismic refraction and georadar were utilized in conjunction with MTO borehole information for calibration/comparison purposes (see Figures 1 and 2).

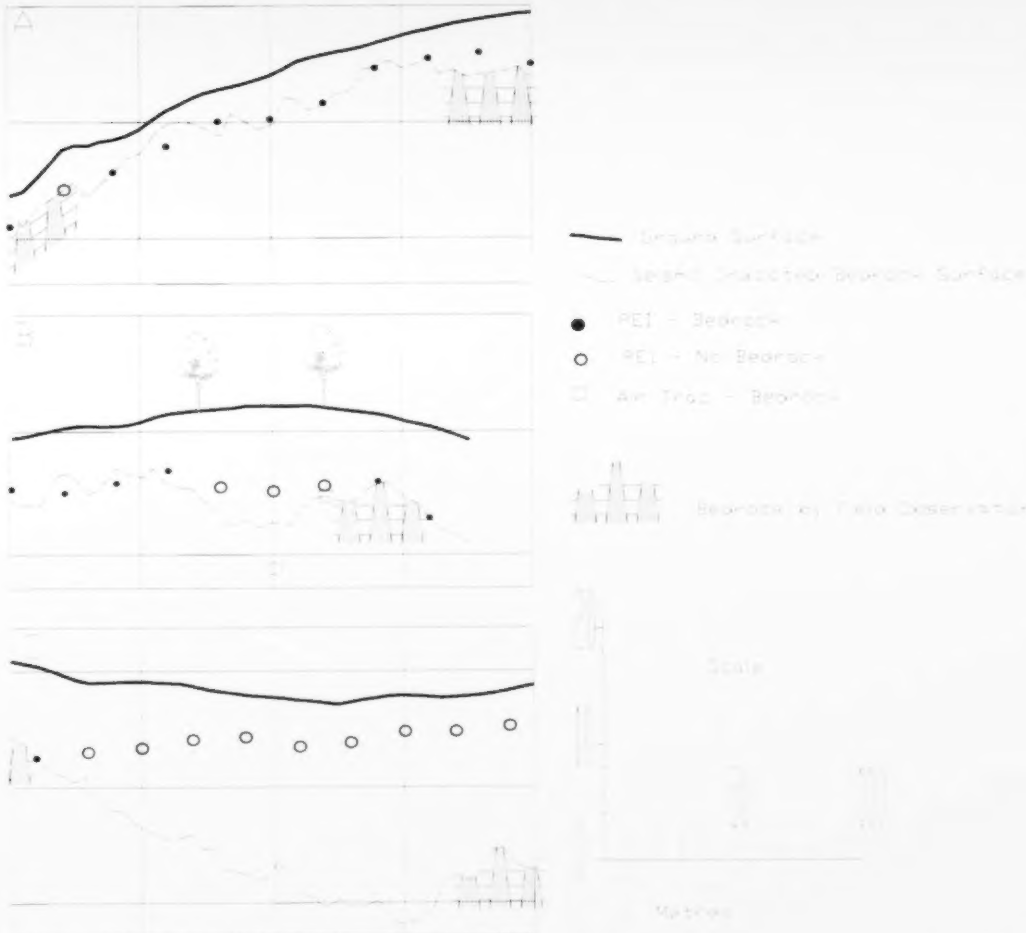
The quality of the seismic refraction data was very good. The radar data was good when bedrock was relatively close to the surface. In general, seismic refraction is the preferred technique since it is better capable to determining bedrock at greater depths. In general, there was a good correlation between the seismic, radar data, and the power equipment information in both of the trial site areas.

Figure 7 shows some of the seismic refraction results for work carried out in the Sundridge area. The top plot (A) in Figure 7 reveals good correlation between the power equipment information and the seismic reflection data with minor exception. The middle plot (B) in Figure 7 generally shows acceptable correlation between the seismic data and power equipment information. The only exception is a deep bedrock valley (13 metres) that was identified by air track drilling. Both the georadar and the seismic reflection data did not indicate its presence. The large boulders that masked the bedrock surface may have made the geophysical interpretations difficult.

The final plot (C) in Figure 7 clearly shows the need for power equipment such as air track percussion drilling in order to determine the rock elevation.

When geophysical investigations are used, it is important that a reasonable number of physical determinations (auger, excavator, or percussion drill) are also made. This will aid in the interpretation of the geophysical data and provide assurance that bedrock elevations have been correctly interpreted.

**Figure 7 Seismic Refraction Profiles with Drill and Field Observations Precambrian Terrain, Northern Ontario**



# Recommended Tolerances

An important component of rock line profiling is the establishment of a realistic vertical tolerance. The tolerance would be applicable to all types of boreholes irrespective of subsurface equipment type. The rock line specialist should be able to measure the elevation of rock at any one discrete exploration location within ±0.2 metres. This should average out over the entire length of the job.

A closer tolerance is unrealistic due to uncertainties of actual ground elevation and bedrock surface.

To verify the tolerance for establishing design rock line is achieved, the ministry requires a process to measure the actual elevations at the exact same locations during the construction phase. Returning to the exact location (top of original surface) can be a challenge. The ability to return to the exact same station depends largely on the quality of the surveying method that is utilized. Total station surveying and GPS, if equipped with survey quality receivers, are two common methods of achieving this.

# Rock Line Profiling

The rock line profile will be established based on the information gathered from all observable mapping data collected while undertaking the preliminary field reconnaissance investigation. In addition, all data gathered from primary and secondary boreholes will be utilized for rock line profiling. If geophysical surveying has been utilized to tie in subsurface information gathered from boreholes, the data may be useful for rock line profiling.

The standard MTO two-dimensional (2D) method of computer-assisted drafting (CAD) profile drawing is a DOS-based software known as HDS program, which dates back to 1965. Designers must use extreme care to ensure that the rock line established by the specialist is correctly and accurately entered into the program for the generation of cross-sections and calculation of quantities for the contract.

After the borehole information is entered into HDS and the preliminary design cross-sections are generated, the designer and geotechnical specialist should work together to review/confirm this information. A joint effort in reviewing the preliminary design cross-sections will provide opportunities to correct the rock line information in advance of the detailed design activity. A major advantage of this joint review would be to review the rock line profile to ensure that the geotechnical information has been interpolated correctly and no errors exist in the survey and borehole data. It would also be desirable to have all of the subsurface data presented in a three-dimensional (3D) view that illustrates a horizontal grid stacked vertically so that a digital elevation model for rock line can be created for a 3D surface image.

# Results and Reporting

The results of a rock line investigation should include the following (in paper and electronic format as per MTO standard requirements) within and as an appendix to the Pavement Design Report:

- The location of the project area that was investigated.
- Results of the literature search for all published pertinent information related to rock line establishment in the project area.
- If geophysical surveying was carried out, all information should be included in the report and the traverses should be clearly marked on the aerial photographs.
- All primary and secondary borehole logs should be included in the report.
- The rock line shown on the soils profile should be established using the ground surface profile and all factual subsurface data obtained at specific exploration locations. All of this information is used to establish the rock line. Any interpolation between exploration locations should be made only on the basis of available geologic knowledge of the study area. The use of geophysical techniques is a valuable aid in such interpolation. Any concerns with weathered bedrock surfaces or the presence of large boulders or floating rock slabs should be identified and discussed in the report. Additional exploration (air track percussion drilling equipment) may have to be considered if there is not sufficient knowledge to develop interpretative cross-sections for rock line determination.
- It is imperative that the final rock line profile data is clearly understood by designers and properly utilized in the design process. The geotechnical specialist should work together with the designer to ensure that the preliminary design cross-sections are accurate and that the geotechnical information has been correctly interpreted.
- On complex jobs with new highway alignment, the use of Digital Terrain Modelling is highly recommended. The use of cross-sections, especially in areas of widely varying topography or drift thickness, or both, may lead to significant inaccuracies in bedrock volume estimation.

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# Appendix A

1. Ministry of Natural Resources
Natural Resources Information Centre Toronto
M1-73, Macdonald Block, 900 Bay Street
Toronto, Ontario M7A 2C1
Tel: 1-800-667-1940

2. Ministry of Natural Resources
Natural Resources Information Centre
1st Floor North, Robinson Place
300 Water Street, P.O. Box 7000
Peterborough, Ontario K9J 8M5
Tel: (705) 755-2000 Fax: (705) 755-1677

3. Ministry of Natural Resources
Geomatic Service Centre
5th Floor, South Robinson Place
300 Water Street, P.O. Box 7000
Peterborough, Ontario K9M 8M5
Tel: (705) 755-5000 Fax (705) 755-5014

4. Ministry of Northern Development and Mines
Ontario Geological Survey
Mines and Minerals Information Centre
Room M2-17, MacDonald Block, 900 Bay Street
Toronto, Ontario M7A 1C3
Tel: (416) 314-3800 Fax: (416) 314-3797

5. Ministry of Northern Development and Mines
Mines and Minerals Division, Publication Sales
Level A3, Willet Green Miller Centre
933 Ramsey Lake Road
Sudbury, Ontario P3E 6B5
Tel: (705) 670-5691 Fax:(705) 670-5770

6. Ministry of Northern Development and Mines
Mines and Minerals Division, Mines Group
Level B4, Willet Green Miller Centre
933 Ramsey Lake Road
Sudbury, Ontario P3E 6B5
Tel: (705) 670-5787Fax: (705) 670-5803

7. Ministry of Transportation
Soils and Aggregates Section
Room 220, Building C, 1201 Wilson Avenue
Downsview, Ontario M3M 1J8
Tel: (416) 235-3735 Fax: (416) 235-4101

8. Ministry of Transportation
Pavements and Foundations Section
Room 232, Building C, 1201 Wilson Avenue
Downsview, Ontario M3M 1J8
Tel: (416) 235-3533 Fax: (416) 235-3919

9. Ministry of the Environment
Public Information Centre
1st Floor, 135 St. Clair Avenue West
Toronto, Ontario M4V 1P5
Tel: (416) 325-4000 Fax: (416) 325-3159

10. Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario K1A 0Y7
Tel: (613) 943-8826 Fax: (613) 943-8828

11. Canada Map Office
Department of Energy, Mines and Resources
615 Booth Street
Ottawa, Ontario K1A 0E9
Tel: (613) 952-7000 Fax: (613) 957-8861

12. Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8
Tel: (613) 922-8914 Fax: (613) 996-8748

13. Geological Survey of Canada
Cordilleran Geology Division
100 West Pender Street
Vancouver, British Columbia V6B 1R8
Tel: (604) 666-0271 Fax: (604) 666-1124

14. Geological Survey of Canada
Institute of Sedimentary and Petroleum Geology
3303-33 Street NW
Calgary, Alberta T2L 2A7
Tel: (403) 292-7000 Fax: (403) 292-5377

15. Geological Survey of Canada
Head, National GEOSCAN Centre
Department of Energy, Mines and Resources
601 Booth Street
Ottawa, Ontario K1A 0E8
Tel: (613) 922-8916 Fax: (613) 996-8748

16. Geological Survey of Canada
Geophysics Division
1 Observatory Crescent
Ottawa, Ontario K1A 0Y3
Tel: (613) 995-5548 Fax: (613) 992-8836

17. National Air Photo Library
615 Booth Street, Suite 180
Ottawa, Ontario K1A 0E9
Tel: (613) 995-4560 Fax: (613) 995-4568

18. Energy, Mines and Resources Canada
Legal Survey Office
50th Street, Bellanca Building, 8th Floor, P.O. Box 668
Yellowknife, Northwest Territories X1A 2N5
Tel: (403) 920-8295 Fax: (403) 873-9949

19. CANMET Publications Sales Unit
Library & Documentation Services Division
526 Booth Street
Ottawa, Ontario K1A 0G1
Tel: (613) 992-6793 Fax: (613) 952-2587

20. Canada Centre for Inland Waters
Canadian Hydrographic Service
Bayfield Laboratory for Marine Science and Surveys
867 Lakeshore Road
Burlington, Ontario L7R 4A6
Tel: (416) 336-4811 Fax: (416) 336-4819

21. National Research Council
Institute for Research in Construction
Ottawa, Ontario K1A 0R6
Tel: (613) 993-2607 Fax: (613) 954-5984